

"Express Mail" Mailing Label No. EV 303437178 US

November 15, 2003

Date of Deposit

Our Case No. 11470-4

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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE
APPLICATION FOR UNITED STATES LETTERS PATENT

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TITLE: A REGULAR ARRAY OF
MICROSCOPIC STRUCTURES
ON A SUBSTRATE AND
DEVICES INCORPORATING
SAME

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A REGULAR ARRAY OF MICROSCOPIC STRUCTURES ON A SUBSTRATE AND DEVICES INCORPORATING SAME

RELATED APPLICATIONS

[0001] The present application is a continuation-in-part application of currently pending U.S. Application 10/168,239, filed June 17, 2002, which claims the benefit of priority to PCT/GB01/00222 filed January 23, 2001 by K. J. Snowden et al., and entitled "Method of forming regular array of microscopic structures on a substrate." Each of the foregoing applications are hereby incorporated by reference as if reproduced in full below.

BACKGROUND

[0002] The present application relates to a device having a substantially regular array of microscopic structures on a substrate and a method of making such an array. The application relates particularly, but not exclusively, to formation of nanometer sized wire-like structures on a substrate.

[0003] Patterned surface structures on articles have applications in the fabrication of various devices, for example data storage media, microelectronic and micro-electromechanical devices, sensors, optoelectronic display devices, and other optical and optoelectronic components such as optical components for directing atomic beams, as well as applications in tissue engineering and for cell adhesion or non-adhesion, or for guiding motion or growth of cells, liquids or molecules, or in molecular scale filters. Known patterning processes involve optical lithography processes or direct-write patterning techniques such as electron beam lithography and scanning probe methods.

[0004] However, optical lithography processes suffer from the drawback that they are of limited resolution, and direct-write patterning techniques, although capable of achieving higher lateral resolution than optical lithography, are impracticable for use in mass production applications because the serial nature of the surface modification process

is inherently slow. Also, when applied to larger areas of material, for example more than a few square centimeters, such processes suffer poor large scale dimensional accuracy, and in the case of patterning formed by step and scan techniques, poor registration between separate write operations and scanned regions is achieved.

BRIEF SUMMARY

[0005] The above disadvantages and more may be overcome by the different embodiments disclosed here. One advantage of the present embodiments is that the surface layer from which the structures are to be formed can be formed at substantially the same time as the formation of the substantially regular array of structures, by carrying out both using the same particle beam or beams.

[0006] The method may further comprise adjusting the direction of at least a first particle beam relative to the surface layer.

[0007] This provides the advantage of enabling the nature and/or formation of the substantially regular array of structures to be adjusted.

[0008] The adjustment may comprise rotating the surface layer relative to at least one of the particle beams.

[0009] The method may further comprise moving at least the first particle beam relative to the surface layer.

[0010] The moving of the first particle beam may comprise scanning the beam across the surface layer, or moving the surface layer relative to the first particle beam.

[0011] The method may further comprise mounting the substrate to an grounded support.

[0012] This provides an advantage in that under certain circumstances at least one particle beam may impact on the grounded support, which may result in at least partial neutralization of electrostatic charge building up on the surface layer or on the substrate.

[0013] The method may further comprise stabilizing the substantially regular array of structures.

[0014] In another embodiment, an array of structures on a substrate comprises a surface layer of a first material on the substrate, the substrate formed of a second material, wherein the structures are substantially regular, the surface layer is sufficiently thin such that stress fields at an interface of the surface layer and the substrate cause formation of separated regions of the first material on the substrate, and at least one of a direction of alignment of the separated regions and a relative position of adjacent separated regions is dependent on at least one particle beam directed onto the surface layer at an acute angle thereto.

[0015] The structures may be approximately 2 atoms in height and/or approximately 10 nm in separation. The array of structures may further comprise at least one protective coating disposed on the at least one surface layer. The surface layer may be disposed on a crystal plane of the substrate. For example, the surface layer may be disposed on a (111) crystal plane of the substrate.

[0016] A plurality of layers may be disposed on the substrate. Each layer may be formed from the first material and/or comprise structures that are substantially regular and substantially linear, or substantially linear rows of dot-like structures. The structures of adjacent layers may be disposed at angles to each other, for example adjacent layers may be at right angles to each other or other angles, for example 120 degrees. The structures of at least two of the adjacent layers may be arranged directly on each other or at least one intermediate layer may exist between the structures of at least two of the adjacent layers.

[0017] Gaps in the surface layer may be filled by at least one of at least one gaseous material adsorbed into the gaps and material that has been deposited into the gaps. The at least one surface layer may have an area larger than a few square centimeters. The at least one surface layer may contain a third material deposited on the at least one surface layer

from a source other than a source from which the first material is deposited.

[0018] The first material may be calcium or calcium-rich or a semiconductor, insulator or another metal. The second material may be calcium fluoride or a semiconductor, insulator or metal.

[0019] A high density memory device may comprise the array of structures. For example, a computer or image capture device may include a high density memory device of the present invention. Electronic filters, optical devices, communications devices such as mobile telephones, automobiles and home appliances are additional non-limiting embodiments of devices that may also incorporate the present inventions.

[0020] In another embodiment, an array of structures on a substrate comprises at least one surface layer containing at least a first material on the substrate, the substrate formed of a second material, wherein the structures are substantially regular and substantially linear, or substantially linear rows of dot-like structures, the first material is formed in separated regions, and the first material contains one of a metal or a semiconductor. For example, the first material may comprise calcium.

[0021] The structures may be approximately 2 atoms in height and/or approximately 10 nm in separation, ranging up to approximately 10 atoms in height and/or 50 nm in separation. The first material may comprise a metal, be metal-rich, or comprise a semiconductor. For example, the first material may comprise calcium or be calcium rich. The second material may be calcium fluoride or an insulator or semiconductor. The surface layer may be disposed on a crystal plane of the substrate, for example the (111) crystal plane of a substrate.

[0022] A plurality of layers may be disposed on the substrate. Each layer of the plurality of layers may be formed from the first material and/or comprise structures that are substantially regular and linear. The structures of adjacent layers may be disposed at right angles to each other. The structures of at least two of the adjacent layers may be arranged directly

on each other or at least one intermediate layer may exist between the structures of at least two of the adjacent layers.

[0023] Gaps in the surface layer may be filled by at least one of at least one gaseous material adsorbed into the gaps and material that has been deposited into the gaps. The at least one surface layer may have an area larger than a few square centimeters. The at least one surface layer may contain a third material deposited on the at least one surface layer from a source other than a source from which the first material is deposited. The array may further comprise at least one protective coating disposed on the at least one surface layer.

[0024] In another embodiment, a surface patterning apparatus comprises a vacuum chamber, at least a first particle source disposed within the vacuum chamber, and a rotatable support disposed within the vacuum chamber and that has a large enough area to enable a substrate to be attached thereto. The first particle source is disposed at an acute angle with respect to the support and the angle and a type and energy of particles from a particle beam of the at least the first particle source are selected such that structures of a surface layer formed on the substrate are substantially regular, the surface layer is sufficiently thin such that stress fields at an interface of the surface layer and the substrate cause formation of separated regions on the substrate, and at least one of a direction of alignment of the separated regions and a relative position of adjacent separated regions is dependent on the angle of the first particle source.

[0025] The surface patterning apparatus may further comprise a motor to rotate the support. The surface patterning apparatus may further comprise a second particle source disposed within the vacuum chamber such that particles in a particle beam from the second particle source impinge on the substrate. Particles from the second particle source may be different from the particles from the first particle source. The second particle source may be disposed at a different angle than the first particle

source. The second particle source may be disposed approximately perpendicular to the support. The first particle source and the second particle source may be disposed such that material from the first particle source and the second particle source are deposited at the same time. The first particle source and the second particle source may be disposed such that material from the first particle source and the second particle source are deposited independently from one another. The first particle source may be disposed at an angle of approximately 10° with respect to the support. The particles from the first particle source may be argon ions. The argon ions may have a kinetic energy of approximately 4,500 eV.

[0026] A vacuum in the vacuum chamber may be approximately 4×10^{-8} mbar. The support may be grounded. The first particle source may deposit calcium, calcium-rich material, another metal, or a semiconductor on the substrate. The first particle source may deposit material on the substrate sufficient to form structures that are generally parallel to a projection of an axis of the particle beam on the substrate.

[0027] In another embodiment a substantially regular array of structures on a substrate is formed by a method comprising providing a surface layer of a first material on a substrate of a second material, wherein the surface layer is sufficiently thin that stress fields at an interface of the surface layer and the substrate cause formation of separated regions of the first material on the substrate, and directing at least a first particle beam onto the surface layer and at a respective acute angle thereto to influence at least one of a direction of alignment of the separated regions and a relative position of adjacent separated regions.

[0028] The providing the surface layer may comprise depositing the surface layer on the substrate. The surface layer may be deposited using at least a second particle beam. The providing the surface layer may comprise modifying the surface of the substrate using at least one particle beam. The surface of the substrate may be modified using at least the first particle beam. The method may comprise adjusting a direction of at least

the first particle beam relative to the surface layer. The adjusting may comprise rotating the surface layer relative to at least the first particle beam. The method may further comprise moving at least the first particle beam relative to the surface layer. The moving may comprise scanning at least the first beam across the surface layer or moving the surface layer relative to at least the first particle beam.

[0029] The method may further comprise mounting the substrate to a grounded support.

[0030] The method may further comprise stabilizing the substantially regular array of structures. The stabilization may include application of at least one protective coating. The stabilization may include chemical modification of the substantially regular array of structures.

[0031] The method may further comprise at least partially filling at least some gaps between the adjacent structures of the substantially regular array. The filling may comprise adsorbing at least one gaseous material into the gaps and/or depositing material into the gaps.

[0032] The method may further comprise directing at least two first particle beams onto the surface layer, wherein the at least two first particle beams are not parallel to each other.

[0033] The method may further comprise the forming of a plurality of the substantially regular arrays of structures. The plurality of substantially regular arrays of structures may be arranged in separate layers.

BRIEF DESCRIPTION OF THE DRAWINGS

[0034] Figure 1 is a schematic view of an apparatus for carrying out a process of a first embodiment;

[0035] Figure 2 is the surface of a structure formed using the apparatus of Fig. 1; and

[0036] Figure 3 is a schematic view of an apparatus for carrying out a process of a second embodiment.

DETAILED DESCRIPTION

[0037] Referring to FIG. 1, a surface patterning apparatus 1 for forming nanometer sized structures of calcium or calcium-rich material on the surface of a substrate of calcium fluoride comprises a vacuum chamber 2 containing a particle beam source 3 for irradiating a sample 4. The particle beam source 3 directs a particle beam 5 at an angle α onto sample 4, which is mounted to a support 6 such as a grounded aluminum support. The support 6 can be rotated by means of a suitable device 7 such as a motor, the purpose of which will be described in greater detail below.

[0038] The operation of the apparatus 1 shown in FIG. 1 will now be described by means of the following example.

[0039] EXAMPLE

[0040] A sample 4 of calcium fluoride was produced by cleaving a calcium fluoride crystal in air at room temperature and pressure, by striking the crystal with a sharp instrument along a direction that generally coincided with the intersection of a (111) crystal plane with one of the crystal surfaces. The freshly cleaved sample 4 was then placed in the vacuum chamber 2 which was evacuated to a pressure of approximately 4×10^{-8} mbar, and the major residual gas components of which were hydrogen and water vapor. Introduction of the sample 4 into the vacuum chamber 2 was assisted by the use for sample introduction of an intermediate small vacuum chamber (not shown) that could be rapidly evacuated to a pressure of approximately 10^{-3} mbar.

[0041] The sample 4 was mounted to a support 6 comprising an electrically grounded aluminum plate, and was irradiated under an angle of incidence α of approximately 10° to the sample surface by a beam 5 of singly positively charged argon ions having a kinetic energy per incident ion of approximately 4,500 electron volts (eV). The sample 4 was held

fixed relative to the support 6. The sample 4 as shown in FIG. 2 was removed from the vacuum chamber 2 and examined by means of a commercially available atomic force microscope, equipped with ultra sharp silicon probe tips supplied by NT-MDT Co. Moscow, having a nominal tip end radius of less than 10 nm. Examination of the sample 4 revealed arrays of linear structures which were always found to be generally parallel to the projection of the axis of the ion beam 5 on the sample surface 4, and to be approximately two atoms in height and approximately 10 nm in separation.

[0042] The method described with reference to FIG. 1 can, under certain circumstances, also be used to form multiple layers of such structures by means of sequentially carrying out the method of FIG. 1 described above. For example, the formation of superimposed layers of wire-like structures (arranged directly or indirectly on top of each other) generally at right angles to each other could be used to construct high density memory devices or optical devices or electronic filter devices.

[0043] Referring now to FIG. 3, in which parts common to the embodiment of FIG. 1 are denoted by like reference numerals but increased by 100, a surface patterning apparatus 101 for carrying out a method of a second embodiment of the invention also includes within vacuum chamber 102 a second beam source 108, being a source of atoms, molecules or clusters which are deposited on the surface of sample 104 by means of a second beam 109. This allows material to be deposited on the surface of sample 104 at the same time as, or independently of, irradiation of the sample 104 by means of the first ion beam 105. In the case of the apparatus 101 of FIG. 3 being used in connection with materials where the stress field between the surface layer and the substrate would tend to cause the formation of compact, non-elongated regions of the material forming the surface layer, for example semiconducting materials, by rotating the sample 104 relative to the ion beam, it is possible to create a substantially regular lattice of dot-like

structures. For example, stress fields at the interface can lead on their own to spontaneous formation of either elongated (wire-like) structures or compact (dot-like) structures. A particle beam incident at a small angle to the surface plane can effectively 'comb' the wire-like structures to become straighter, less branched, and acquire more regular widths and separations. A particle beam can also be used in the same way to align dot-like structures in rows. Use of two (or more) such beams incident from different directions (e.g. at right angles or at 120 degrees to each other) can assist the formation of regular 2 dimensional arrays of such dots (e.g. 2 beams at right angles or one beam rotated repeatedly between two dwell positions produce a 'square' array of dots, 3 beams or one beam rotated between three dwell positions 120 degrees to each other produce a hexagonal array of dots

[0044] It is therefore intended that the foregoing detailed description be regarded as illustrative rather than limiting, and that it be understood that it is the following claims, including all equivalents, that are intended to define the spirit and scope of this invention.